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A Rational Approach to Corrosion Protection of the Concrete Components of Highway Bridges

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A Rational Approach to Corrosion Protection of the Concrete Components of Highway Bridges

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Abstract:	The deterioration of highway structures, primarily as a result of the corrosion of the embedded reinforcement, has resulted in changes in materials, design, and construction techniques with the intent of improving durability. This paper traces the development of corrosion protection requirements in Ontario over a 30-year period. The methods of acheiving positive protection for superstructure and substructure components are presented, including warrants for the use of epoxy-coated reinforcement, the use of increased concrete cover, the adoption of higher qualities of concrete, and increases in member thickness. The result of implementing these changes has been the evolution of a rational approach to durability of highway bridges, of which corrosion protection is a vital component. Corrosion protection is provided in individual components according to the severity of the service environment and, in the most severe exposure conditions, includes multiple protection systems such that redundancy is provided.
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A Rational Approach to Corrosion Protection of the Concrete Components of Highway Bridges

By David G. Manning

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INTRODUCTION

In common with other parts of North America where deicing chemicals are used in winter maintenance operations, Ontario has experienced rapid and premature deterioration of highway structures. Corrosion-induced deterioration, which first became apparent in bridge decks, is now also a serious problem in other concrete components. The design, construction and maintenance standards used in the 1950's and 60's were insufficient to produce bridges with a long life and low maintenance costs. While deficiencies such as poor drainage, joint leakage, inadequate cover, and concrete of questionable quality contributed to the ingress of chloride ions and the corrosion of embedded reinforcement, the underlying cause has undoubtedly been the failure to recognize the severity of the service environment for highway bridges.

This paper traces the development of Ontario's approach to corrosion protection in highway bridges, beginning with the period of problem recognition and concluding with current practices.

BACKGROUND

In Canada, highways are under provincial jurisdiction. Consequently, each province is responsible for its own policies and funding. In Ontario, funding is apportioned from provincial tax revenue and is independent of gasoline taxes. In the context of this paper, the significance of jurisdiction is that changes in corrosion protection occur only at the initiative of the Ministry of Transportation and Communications (MTC) and that the total cost must be borne by Ontario taxpayers. A positive aspect, however, is that the absence of financial participation by other levels of government, means changes can be implemented relatively quickly.

Bridge deck deterioration is not a new phenomenon. As early as 1963, deficiencies were being identified in bridge decks in the MTC system. A major investigation (1) found widespread deter-

ioration of the concrete beneath the bituminous concrete surfacings then in use. It is important to note that the most common type of deterioration was not the corrosion of embedded reinforcement, but severe scaling of the concrete. Ontario was rather late in introducing air-entrainment to highway structures and did not require its use until 1958 though a lignosulfonate admixture had been in routine use for many years previously. The introduction of air entrainment coincided with the first use of sealers beneath the bituminous concrete. The sealers were found to be ineffective (2) and soon gave way to membranes. Field investigations of the early membranes revealed numerous failures, especially adjacent to the curb (3). The inability to inspect the upper deck surface was also considered a major disadvantage and the decision was made to construct exposed concrete decks. The first exposed concrete deck was constructed as an experimental project in 1963 and bare decks became the standard form of construction in 1965. With the introduction of exposed decks, deck thickness was increased from 7 in. to 7 1/2 in. and the specified minimum cover from 1 in. to 1 1/2 in.[1]. The additional 0.5 in. was considered an allowance for wear. The concrete was specified to have a minimum 28 day strength of 4000 lb. $in.^{-2}$. However, a minimum cement factor of 612 lb. $yd.^{-3}$ ensured that the water-cement ratio was approximately 0.45. Although the use of a bituminous surfacing was curtailed, all new decks continued to be designed with provision for a future 3 in. thick surfacing.

Decks with an exposed concrete surface were built between 1965 and 1972. During this period, the major expansion of the freeway system took place and almost one-quarter of the bridges under provincial jurisdiction were constructed in those years. By the early 1970's, it was clear that the deck slabs were prone to corrosion of the embedded reinforcement. In some cases, major rehabilitation contracts, costing as much as the original deck, were required within ten years of construction. There was no question that improved protection against corrosion had to be provided and that the method chosen had to be capable of immediate implementation. The decision was made to apply a waterproofing membrane and a bituminous surfacing to all new decks. The Ministry had gained experience with new types of waterproofing membranes in rehabilitation contracts in the late 1960's and the flexible, hot-applied rubberized asphalt membranes appeared very promising (4). Since all structures had been designed for future overlay, stockpiled designs did not have to be re-designed and, through change orders, the membrane could be added to contracts already awarded.

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[1]Units given are those in use at the time the policy was implemented or those used in the source material. The change to metric units in bridge construction took place in 1977. Conversion factors are given at the end of the paper.

In retrospect, early corrosion damage in exposed deck slabs with very shallow covers (the 1 1/2 in. specified minimum was rarely achieved) and subjected to frequent applications of deicing chemicals should have been predictable. However, it must be remembered that the design details used in bridge decks in Ontario were considered state-of-the-art throughout North America. Indeed, such details continued to be used in similar exposure conditions in private sector work for another decade. The important lesson to be learned from these experiences is that the durability of reinforced concrete is determined by the effect of all aspects of the service environment on all the constituents of the composite material. The action taken to correct the scaling deterioration in 1963 precipitated corrosion-induced deterioration in the late 1960's and early 1970's and this emphasizes the dangers of viewing deterioration mechanisms in isolation and loosing sight of the overall requirement for durability.

The deck details were modified slightly in 1973 when it was found that the waterproofing membrane was sometimes damaged by the paving equipment when the bituminous surfacings were applied. Cores taken from wheel track areas also showed that the membrane was susceptible to the gradual penetration of larger stone particles from the hot mix. As a result of these observations, a protection board, consisting of asphalt-impregnated felt approximately 1/4" thick was placed directly on the membrane on a trial basis in 1973 and made standard in 1974.

CHANGES IN THE PERIOD 1975-1979

Recognizing that the measures taken in 1972 were largely the result of expediency and that the technology for improving the durability of bridge decks was changing rapidly, especially in the U.S., the Ministry initiated a more systematic approach to bridge deck durability in the mid 1970's. The first step was a research project to prepare a state-of-the-art report (5) which documented the mechanisms of bridge deck deterioration and examined the options for achieving durability in new construction and in rehabilitation. The major impact of the study on new construction was an immediate increase in the specified cover for the top mat of deck reinforcement and the recommendation of two stage construction as the most promising option for new construction. As a result, a demonstration program was undertaken in 1976 and 1977 to evaluate the suitability of low slump concrete, latex modified concrete and internally sealed concrete as the second stage in two stage construction and as a means of rehabilitating deteriorated decks (6).

During the winter of 1977-8, the experience of the previous two years was carefully reviewed and significant changes were made in the Ministry's policies for corrosion protection in new construction and for the repair of corrosion-induced distress in existing structures. The experience gained following the demonstration projects with two stage construction led to the

decision not to implement this technique. Not only was two stage construction found to be expensive, but the temperature restrictions limited overlay construction to the period May to September and this was not acceptable for new construction. The experience was, however, applicable to rehabilitation and concrete overlays (except for internally sealed concrete which was found impractical) constitute one of the options routinely used in rehabilitation contracts (7).

Perhaps the most significant decision made in the review process was the acknowledgment that the bridge deck environment constituted such a severe exposure condition for reinforced concrete that a single method of corrosion protection was unlikely to be adequate and that a conservative approach was justified. It was recognized that not only were repairs expensive, but that rehabilitation contracts caused serious disruption to traffic flow and that, even after repair, a structure was inferior to a structure which had not deteriorated. A multiple approach to corrosion protection was developed which consisted of:

i) maximizing the protection provided by the concrete,

ii) using epoxy coated reinforcement in selected locations,

iii) continuing to use a waterproofing membrane on bridge decks.

The details and the rationale behind this approach follow.

Quality of Concrete

The bridge deck environment constitutes a very severe exposure condition for concrete. It is subjected to wetting and drying, freezing and thawing, and applications of deicing chemicals. In addition, there are large temperature gradients and high live load stresses. Poor drainage often increases the degree of saturation of the concrete and aggravates the consequences of frost action. To be durable, the concrete must have a good air void system and a low water-cement ratio.

The degree of protection provided by the concrete against corrosion is a function of the depth of cover to the reinforcing steel and the permeability of the concrete (8,9). Concrete permeability depends upon numerous factors though the most important are water-cement ratio, degree of consolidation, and adequacy of curing.

The combined effects of water-cement ratio and depth of cover for a properly consolidated concrete are shown in Figure 1. The figure illustrates the number of daily applications of sodium chloride to specimens in an outdoor exposure plot before the reinforcing steel began to corrode. For a concrete with a water-cement ratio of 0.40, 40 mm of cover was found sufficient

to prevent corrosion of the steel for 800 applications of salt (10). Equivalent protection was afforded by 70 mm of concrete with a water-cement ratio of 0.50, or 90 mm of 0.60 water-cement ratio concrete.

It is Ministry practice to specify concrete quality by classes, each of which has a strength requirement (at 28 days) and a minimum cement content. 20 MPa concrete requires a minimum cement content of 310 kg/m^{-3} and typically has a water-cement ratio of 0.50. The corresponding figures for 30 MPa concrete are 355 kg/m^{-3} and 0.45. For 35 MPa concrete, they are 415 kg/m^{-3} and 0.40, respectively. On the basis of the work shown in Figure 1, 30 MPa concrete was selected for reinforced concrete deck slabs and 35 MPa for prestressed slabs. In the highway environment, protection against corrosion will often require a lower water-cement ratio than is necessary to satisfy the strength requirements of the structural member. It is also important to note that although resistance to penetration by chloride ions is substantially improved as the concrete permeability decreases, it is not possible to upgrade the quality of concrete sufficiently using conventional materials and construction procedures to render it impermeable.

Concrete Cover

ACI Recommended Practice for Concrete Highway Bridge Deck Construction (11), recommended 2 inches of clear cover to the top reinforcing steel with due account being taken of deviations from specified cover, $\pm$ 1/2 in. being considered normal. A specified cover of 2 1/2 in. $\pm$1/2 in. was implemented in Ontario in 1975. The justification of the selection of a cover of 2 in. was confirmed by the work shown in Figure 1.

In 1976, a survey of concrete cover was undertaken to determiine the degree of compliance with the new specification (12). Individual decks varied between 18 and 100 percent compliance (i.e. for the worst deck, only 18 percent of the cover measurements were within the specified range of 2 1/2 $\pm$ 1/2 in.). The study concluded that the concrete cover to the top steel placed by a diligent contractor was normally distributed with a standard deviation (σ) of a figure confirmed by investigations elsewhere (13).

An acceptance criterion was defined to allow not more than 2.5 percent of the measurements to be less than the specified minimum cover. This acceptance criterion means that 95 percent of the bars must be within the range of average cover $\pm 1.96\sigma$. This led to a change in the specified cover to the top mat of reinforcing steel to 2 3/4 in. $\pm$ 3/4 in. to better reflect the tolerances which could reasonably be expected in construction.

The change in specified cover was accompanied by requirements which would make the specification easier to achieve and the introduction of quality assurance requirements to verify the

cover. These changes included tying each mat of steel at every second intersection point. On thin slab decks, the two mats were tied together and to the beams. On thick slab decks, bending schedules were changed to reduce the height of stirrups. The changes in quality assurance practices included a dry run with the screeding machine, a requirement that the contractor could not place concrete until written permission was received from the inspector, the use of tell-tales during concrete placement, and pachometer measurements of the hardened concrete.

Changes in Structural Design and Thickness of Deck Slabs

The Ontario Highway Bridge Design Code (OHBDC), a limit state code introduced in 1979 (14), represented a fundamental change in bridge design philosophy. Among the changes was a provision which permitted an empirical approach to the design of thin slab decks provided that certain boundary conditions were satisfied. Within the defined constraints, 0.3 percent isotropic reinforcement in the top and bottom mats was deemed to satisfy the design requirements. The major implication of this change in terms of corrosion protection was that the option of coating the reinforcement became much more economical.

At the same time that the changes in specified cover were being considered, the requirements for minimum deck thickness were also examined to take account of anticipated construction tolerances. The starting point for determining the minimum deck thickness was the specified minimum covers in the OHBDC of 50 mm and 30 mm for the top and bottom mats, respectively. It was then assumed that: the tolerance for placing the top mat steel was $\pm$20 mm; for the bottom mat $\pm$10 mm; that 20M bars would be used for most decks; and the separation between the mats would be not less than 25 mm to allow for the use of nominal 19 mm aggregate.

As shown in Figure 2(a), if average covers were maintained, the minimum required deck thickness would be 215 mm. However, if maximum clearances to the top and bottom steel occur simultaneously, the minimum required deck thickness is 225 mm, even when the longitudinal bars are staggered to maintain the clearance between the mats. Since no allowance was specifically made for the variations of the concrete slab thickness, which could be $\pm$10 mm, it was decided that it was reasonable to design for a speci-fied minimum deck thickness of 225 mm. These changes were implemented in 1981.

Epoxy-Coated Reinforcement

The use of epoxy coated reinforcing bars was developed from a laboratory study by the National Bureau of Standards in the early 1970's (15). The first installation of epoxy coated bars in a bridge deck was in Pennsylvania in 1973. At the time the state-of-the-art report (5) was prepared in 1975, epoxy coated reinforcement was identified as a promising method of deck protection but no action was taken because the bars were

relatively expensive and there was no Canadian producer. The decision was made not to use imported bars in a demonstration project because the resources were better utilized to monitor the experience in U.S. jurisdictions.

By the fall of 1977, 17 states had adopted the use of epoxy coated bars as a standard procedure, and a further 9 states had installed coated bars on an experimental basis. The rapid expansion in the market resulted in several new coating facilities and a substantial reduction in cost.

Following the evaluation of several alternatives, the decision was made in April 1978 to use epoxy coated reinforcement in the top mat of deck slabs and in curbs and barrier walls. The use of the coated bars was calculated to increase the cost of the structure by 1.8%. It should be noted that the use of coated bars was viewed as additional corrosion protection and there was to be no reduction in concrete quality or cover. The 1.8% premium was regarded as a modest insurance premium especially when considered over the life of the structure.

The implementation date was set for contracts awarded after November 1, 1978. Where feasible, negotiations were undertaken with the contractor to include coated bars in contracts awarded prior to November 1978. At the time the decision was made to use epoxy coated bars, no facilities for coating rebars were available in Canada. Preliminary discussions with industry representatives had, however, indicated an interest in building a coating facility in Ontario. A plant specifically designed for coating reinforcing steel was designed and constructed in 1978 and began production in early 1979. A second coating plant commenced production in 1981.

Rapid implementation of the use of coated reinforcement was made possible by the fact that bridges already designed did not have to be re-designed because of changes in dead load, proven materials were available, and few changes in construction procedures were required. A general policy of coating all bars within 100 mm of a surface exposed, or potentially exposed, to salt was established. A detailed review of structural drawings was undertaken to define which bars were affected and the changes were incorporated in the Ministry's Structural Manual. Plans were modified to identify coated bars by the letter "C" following the bar number and computer programs were changed to calculate the quantities of coated and uncoated bars separately. Specifications were written and quality assurance and approval procedures for the coating materials and the finished product were developed.

During the winter of 1978-9, training courses were given to construction personnel to familiarize them with the use of epoxy coated reinforcement and acceptance requirements. The emphasis was placed on avoiding damage to the coating rather than relying on the touch-up of damaged areas in the field. Initially, the

interpretation of the specification caused some difficulties and disputes arose when shipments were rejected. However, the situation settled down as contractors and inspectors became more familiar with the product and the acceptance requirements. A report (16) dealing specifically with the acceptance of epoxy coated bars has been useful in avoiding disputes in recent years.

SUBSTRUCTURE COMPONENTS

Although the bridge deck problem and the development of solutions received most attention between 1975 and 1978, it was becoming increasingly obvious during that period that other concrete components in bridges were vulnerable to chloride induced corrosion. Serious corrosion spalling problems to the columns and piers of major structures in Southern Ontario plus the general condition of substructure elements on many older bridges dictated the need for additional protection to parts of the bridge below the deck slab. Deterioration has been observed in substructure components where chloride contamination has occurred from surface runoff passing through leaking deck joints, or poorly sited drainage pipes, or by splash from adjacent roadway surfaces (17). It is especially difficult to achieve watertight deck joints (18) and, although improvements in performance are being made, it is prudent to design abutments and piers at which joints are located with additional protection against corrosion.

A number of systems to provide the required protection to substructure elements were considered. These included: permanent, non-corrosive forms on some elements such as columns; concrete sealers, corrosion inhibiting admixtures, epoxy coated bars and increased cover to the reinforcement.

Permanent forms, concrete sealers and corrosion-inhibiting admixtures were excluded from further consideration because early implementation of protection was required and there was insufficient time to undertake the research necessary to provide assurances of satisfactory long-term effectiveness of these approaches. A limited survey of the condition, concrete cover, and chloride ion content of piers, abutments and retaining walls was undertaken in 1981. Increased concrete cover was not considered a satisfactory solution for all substructure elements due to flexural cracking under some conditions and the considerable variation in achieved cover in columns and piers reported in the investigation.

After examining a number of alternatives, substructure elements were divided into three groups depending on the severity of exposure.

i) Group 1: Elements directly exposed to salt splash and/or roadway drainage. For the purpose of identifying Group 1 elements, salt splash is considered to affect all elements, or parts of elements, within 10 m of the edge of the roadway, or future widening, and to a height of 5 m above the

roadway. For Group 1 elements, all bars within 100 mm of the affected surface are epoxy coated and the class of concrete is not less than 30 MPa. In practice, for structures in grade separations, this results in the use of coated bars in such elements as bearing seats, ballast walls, abutments, piers, cap beams, columns, and some wingwalls and retaining walls. On river and rail crossings, coated bars are only used in substructure elements beneath deck joints. Even though sealed joints are normally used, the policy for corrosion protection is based on the assumption that joints may leak during the life of the structure. The development of a satisfactory system to fabricate coated steel into spirals for use in circular columns was an important industry initiative which made possible early implementation of the policy.

ii) Group 2: Elements indirectly exposed to salt (generally through windblown roadway spray). Group 2 elements were defined as elements, or parts of elements, within 30 m of the edge of roadway or future widening, but not including Group 1 elements. Wingwalls and some retaining walls are the most common elements in Group 2. For Group 2 elements, the amount of concrete cover was increased to 95$\pm$ 20 mm and the class of concrete to not less than 30 MPa.

iii) Group 3: Elements not exposed to salt. Group 3 elements are typically sections which are buried, and piers, columns, and cap beams of rail or river crossings not under a joint in the bridge decks. No additional protection beyond that required by the OHBDC is provided.

The proposed policy for additional substructure protection was finalized in March 1981 and implemented immediately. Where practical, contracts already awarded were changed through negotiations with the contractor to incorporate the additional protection.

DECK SOFFITS

In the years following the decision to coat only the top mat of reinforcing steel, concerns were expressed periodically as to whether the bottom mat of steel would act as a large cathode to drive macrocell corrosion at defects in the epoxy coating on the top mat. Investigations by others (19) did show that electrical coupling of an uncoated bottom mat and epoxy coated top mat could induce accelerated corrosion. However, this effect became of practical concern only when the bare area of the coated bars exceeded 0.24 percent. Furthermore, the test data were developed in specimens exposed to chlorides from the time of construction to represent the case of an exposed concrete deck. Where a waterproofing membrane is used, the effectiveness of the epoxy coating is extended considerably because of the amount of time required for chlorides to penetrate the membrane and permeate the concrete to the level of the steel. Consequently, it was deter-

mined that there was not sufficient justification to coat the bottom mat of steel. Even with 0.24 percent damaged areas, the service life was projected to be almost 20 times the service life of decks with two mats of uncoated reinforcement.

Questions regarding the use of black steel in the bottom mat were raised again following the implementation of the policies for substructure protection since there was concern that the spray from vehicular traffic which was causing corrosion in columns adjacent to the roadway may also result in the corrosion of the bottom mat of steel in structures in grade separations.

An investigation was initiated in 1983 to measure the chloride content of bridge decks in service. Twenty-seven decks were sampled to represent varying types of deck, age, and exposure condition with respect to surface run-off and salt spray from traffic. The chloride ion content was measured at several horizons and the amount of chloride ion which had penetrated the concrete from the top of the deck and the deck soffit to the currently specified level of the reinforcement was calculated.

In all but four cases, the chloride contamination in the soffits of the decks was below the threshold value for corrosion (20), thereby justifying the continued use of uncoated bars in the bottom mat. There was no relationship between the chloride contamination and deck type, age, location or traffic volume. Even in the older decks (with one possible exception discussed later), some of which were more than 50 years old, chloride entering from the top surface had not penetrated to the bottom mat. In three of the four cases where the chloride contamination exceeded the corrosion threshold value, it was the result of surface run-off flowing from the deck surface through open longitudinal joints or handrails, over the side of the deck and across the soffit. The problem was most acute for thick slab decks on a superelevation, in which case, the whole soffit could be affected. It was found that parapet or barrier walls offered very effective protection to the deck soffits. In the fourth case, the deck was constructed in 1937 and had been extensively repaired and the open railings replaced with concrete parapet walls. One core taken in an areas of the soffit which had not been repaired, showed high chloride values. However, it was not possible to determine whether the high chloride content was the result of salt laden run-off flowing over the side of the deck and across the soffit or salt water seeping through the deteriorated deck before repairs were made, or a combination of both.

The study resulted in a modification to the Ministry's policies for corrosion protection. Decks with parapet or barrier walls were unchanged except for the drip detail shown in Figure 3. This detail proved to be superior in laboratory testing to the detail used previously. Where open railings or longitudinal joints (sealed or unsealed) are used, epoxy coated bars are provided in the soffit of the cantilever section of the slab decks and all the reinforcing steel in the exterior girders is

epoxy coated. In the case of thick slab decks, the amount of bottom steel which must be coated is a function of the slope of the soffit as shown in Figure 3. The number of bars which are required to be coated adjacent to transverse joint was also increased as shown in Figure 4. The discharge from drains onto substructure components was recognized as a specific problem at some sites. However, the magnitude of the problem depends upon such factors as the length of the discharge pipe, the relative positions of the pipes and the piers, the height of the piers and the prevailing wind direction, and it was determined that, within the guideline of providing protection where necessary, these problems were best treated on a site specific basis.

SUMMARY OF POLICIES FOR DURABLE STRUCTURES

In general, Ministry policies for the attainment of durable reinforced concrete construction have two specific objectives:

i) To prevent deterioration of the concrete,
ii) To prevent corrosion of the embedded reinforcement.

The first objective is addressed through a comprehensive program which includes all facets of materials selection, design, construction, inspection and maintenance. Aggregates are carefully screened for resistance to freezing and thawing and deleterious reactions with the alkalis in portland cement. All the mix ingredients must be supplied from approved sources. An appropriate class of air entrained concrete is specified. Design details include the provision of adequate drainage. It is standard practice to use a bituminous concrete surfacing because of dissatisfaction with the riding quality and skid resistance which can be attained with an exposed concrete surface. A waterproofing membrane is used to protect the concrete against freeze-thaw damage because, without the membrane, moisture could be trapped on the deck surface. The membrane also offers some protection against corrosion of the reinforcement. The standard membrane consists of a 5 mm thickness of hot applied rubberized asphalt and is used in conjunction with an asphalt-impregnated protection board.

The second objective is addressed through the selection of the class of concrete appropriate to the exposure conditions, the specification of a cover depth which will delay the ingress of chloride ions to the reinforcement for a substantial period and the use of epoxy coated bars in selected locations. Current (1986) Ministry policies are summarized in Table 1. Table 2 traces the deck protection practices in Ontario over the past 30 years and indicates when significant changes were made.

Good construction practices and rigorous quality assurance procedures to verify the quality of the concrete, the depth of cover, and the integrity of the reinforcement are essential to achieving both objectives. Furthermore, durability considerations do not end once a structure is placed in service. Long

term satisfactory performance can only be achieved through a bridge management program which includes: routine inspections, preventive maintenance such as periodic washing and the cleaning of joints and drains, and prompt action to correct defects throughout the service life of the structure (21).

The implementation of policies to provide positive corrosion protection to structures have inevitably increased the costs of construction. An analysis made in 1981 of the additional costs of coated reinforcement in the deck, piers, and abutments, increased thickness of deck slab and barrier walls and the use of a higher class of concrete in some substructure elements, amounted to as much as 8.5 percent of the value of the structure (22). Changes made since 1981 have been largely made to correct detailing deficiencies which were recognized in a relatively small number of structures. While the cost of these changes can be substantial for specific structures, they have only a minor effect on the total cost of bridge construction.

The multiple protection approach is not without its critics who argue that initial construction costs can be reduced while still retaining an acceptable level of durability. However, the majority opinion within Ontario favors a somewhat cautious approach to ensure durable highway structures given the comparatively poor performance of earlier standards and construction practices that appeared to promise low maintenance structures. Multiple protection is considered not only reasonable but mandatory when the overall quality of bridge construction is appraised critically. It must be recognized that, despite the best intentions of the contractor and the authority, it is impractical to achieve close to perfection in the quality and dimensions of the concrete, the impermeability of the membrane and the integrity of the epoxy coating on the reinforcement. The reasonableness of an approach which includes multiple protection systems can also be justified on the basis of the extreme difficulty in the partial or full replacement of some types of deck slab, especially when prestressing or segmental construction is used.

CONCLUSIONS

Since the rehabilitation of deteriorated structures on a highway network is expensive, technically difficult, and causes inconvenience to the road user, the logical approach is to make every effort to construct bridges that have the characteristics of long life and low maintenance costs. This demands a conservative approach which recognizes the severity of the service environment and the imperfections which occur in even good quality construction.

The developments reported in this paper give room for some optimism as to the long term durability of new construction. There is no doubt that concrete structures being built today, have much better protection against corrosion than those built

only a few years ago. However, there is no room for complacency. Firstly, the performance record of highway structures is no reason for magniloquence. Secondly, we must not permit ourselves to become preoccupied with corrosion protection at the expense of other mechanisms of deterioration which may influence the durability of structures. Finally, research and development must continue within the broad area of structure durability, both at the fundamental level and in monitoring structure performance to determine the actual benefits of design and construction improvements and to determine the need for timely changes in current practices.

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REFERENCES

1. Armstrong, M.D. and Wawrzynski, J., "The Condition of Concrete Bridge Decks in Ontario", Proc. 44th Convention of the Canadian Good Roads Assoc., Winnipeg, pp 142-154, (1963).

2 Smith, P., "Observations on Protective Surface Coatings for Exposed or Asphalt Surfaced Concrete, Highway Research Board Bulletin No. 323, pp 72-94 (1962).

3. Corkill, J.T. and Lee, G. R., "Effectiveness of Bridge Deck Waterproofing in Ontario", Dept. of Highways, Ontario, (1964).

4. Blum, W.E., "Bridge Deck Waterproofing in Ontario", Ontario Ministry of Transportation and Communications Report No. IR50, 13 pp, (July 1972).

5. Manning, D.G., and Ryell, J., "Durable Bridge Decks",Ontario Ministry of Transportation and Communications Research Report 203, 67 pp, (1976).

6. Manning, D.G., and Owens, M.J., "Ontario's Experience with Concrete Overlays for Bridge Decks", Roads and Transportation Association of Canada, Annual Conference Proceedings - Design Volume, pp 61-78 (1977). Reprinted in RTAC Forum, Vol. 2, No. 1, pp 31-37 (1979).

7. Manning, D.G., and Bye, D.H., "Bridge Deck Rehabilitation Manual, Part One: Condition Surveys; Part Two: Contract Preparation; Supplement: Special Provisions and Reference Contracts", Ontario Ministry of Transportation and Communications SP-016, SP-017, and SP-018 (1984).

8. "Guide to Durable Concrete", American Concrete Institute Committee 201, J. of American Concrete Institute, Vol. 74, No. 12, pp 573-609, (1977).

9. NCHRP Synthesis of Highway Practice 57, "Durability of Concrete Bridge Decks", Transportation Research Board, 60 pp (1979).

10. Clear, K.C., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs", Vol. 3, Performance After 830 Daily Salt Applications, Report FHWA-RD-76-70, 64 pp, (1976).

11. "Recommended Practice for Concrete Highway Bridge Deck Construction", American Concrete Institute Committee 345, J. of American Concrete Institute, Vol. 70, No. 6, pp 381-415, (1973).

12. "Task Force on Durable Bridge Decks : Activities During 1976 and 1977", Ontario Ministry of Transportation and Communications Internal Report (1978).

13. Weed, R.M., "Recommended Depth of Cover for Bridge Deck Steel", Transportation Research Record No. 500, pp 32-35, (1974).

14. "The Ontario Highway Bridge Bridge Code - First Edition", Ontario Ministry of Transportation and Communications, (1979).

15. Clifton, J.R., Beeghly, H.F., and Mathey, R.G., "Non-metallic Coatings for Concrete Reinforcing Bars", Report FHWA-RD-74-18, 87 pp, (1974).

16. Saint, E.R., "Guidelines for Inspection, Patching and Acceptance of Epoxy Coated Reinforcing Bars at the Job Site", Ontario Ministry of Transportation and Communications Report No. EM-69, 14pp (1983).

17. Manning, D.G., and Holt, F.B., "Deterioration of Substructures Phase I Ontario Ministry of Transportation and Communications Report No. ME-81-01 (1981).

18. Manning, D.G., and Witecki, A.A., "Requirements for Deck Joints in Highway Structures", Joint Sealing and Bearing Systems for Concrete Structures, American Concrete Institute SP-70, Vol. 1, pp 291-309 (1981).

19. Clear, K.C., FCP Annual Progress Report - Year Ending September 30 1980, Project 4K - "Cost Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments".Federal Highway Administration, (1980).

20. Reel, R.S., and Manning, D.G., "The Chloride Content of Concrete Bridge Decks in Ontario with Particular Reference to Deck Soffits" Ontario Ministry of Transportation and Communications Report No. ME-86-01 (1986).

21. Manning, D.G., and Reel, R.S., "Bridge Management", Ontario Ministry of Transportation and Communications Report No. ONT-013 (1985).

22. Ryell, J., Manning, D.G., and Owens, M., "Durable Highway Structures - Recent Developments in Ontario", Transportation Forum, Vol. 1-1, pp 83-93, Roads and Transportation Association of Canada (1984).

CONVERSION OF UNITS

To Change From	To	Multiply By
in.	mm	25.4
$lb.in.^{-2}$	MPa	0.00703
$lb.yd.^{-3}$	$kg\ m^{-3}$	0.593

Table 1: Corrosion Protection Requirements for Concrete Components

STRUCTURE COMPONENT	MINIMUM CONCRETE THICKNESS mm	MAXIMUM W/C OF CONCRETE	REINFORCING STEEL TO BE EPOXY COATED	CONCRETE COVER TO STEEL mm	OTHER REQUIREMENTS
Deck	225	0.45 (reinforced) 0.40 (post tensioned)	Top Mat (1)	70±20 (Top Mat) 40±10 (Bottom Mat)	All decks covered with hot applied rubberized asphalt waterproofing membrane, protection board and 80 mm hot mix.
Barrier Wall	200 (Top of Wall)	0.45	All Bars	70±20	
Beams:					
Pretensioned Concrete	---	(2)	All bars within 3 m of a transverse expansion joint (3)	28+5 -3	
Substructure Components:					
Group 1-Elements Directly Exposed to Salt Splash and/or Roadway Drainage	---	0.45	All Bars (4) within 100 mm of Exposed Face	80±20 (Exposed Face)	
Group 2-Elements Indirectly Exposed to Salt	---	0.45	None	95±20 (Exposed Face)	
Group 3-Elements Not Exposed to Salt	---	0.50	None	In accordance with OHBDC	

(1) Epoxy coated steel is also used for the bottom mat in the cantilever portion of thin slab decks for designs with open railings or longitudinal joints. Thick slab decks have additional requirements which are dependent on the superelevation.

(2) Specified by strength, typically 30 MPa at transfer, 40 MPa at 28 days.

(3) Additional requirements for exterior girders for designs with open railings or longitudinal joints.

(4) Components exposed to discharge from deck drains are treated individually.

Table 2: Deck Protection Requirements During the Period 1958-1986

YEAR	CONCRETE STRENGTH (AT 28 DAYS)	THICKNESS OF THIN SLABS	COVER TO TOP MAT	BITUMINOUS SURFACING	OTHER REQUIREMENTS
Pre 1958	3000 lb. in.$^{-2}$	7 in.	min. 1 in.	Yes	Not air entrained, not waterproofed.
1958-61	3000 lb. in.$^{-2}$	7 in.	min. 1 in.	Yes	Air entrainment introduced. Silicone treatment prior to paving.
1961-65	3000 lb. in.$^{-2}$	7 in.	min. l in.	Yes	Mastic asphalt or glass fiber in an asphalt emulsion membrane.
1965-72	4000 lb. in.$^{-2}$	7 1/2 in.	min. 1 1/2 in.	No	Two coats of linseed oil and kerosene at the time of construction.
1972-75	4000 lb. in.$^{-2}$	7 1/2 in.	min. 1 1/2 in.	Yes	Hot applied rubberized membrane. Protection board added in 1974.
1975-78	4000 lb. in.$^{-2}$	7 1/2 in.	2 1/2 $\pm$ 1/2 in.	Yes	
1978-81	4000 lb. in.$^{-2}$	7 1/2 in.	2 1/2 $\pm$ 1/2 in.	Yes	Epoxy coated reinforcement in top mat.
1981-86	30 MPa	225 mm	70 $\pm$ 20 mm	Yes	
1986-	30 MPa	225 mm	70 $\pm$ 20 mm	Yes	Additional requirement for epoxy coated reinforcement in cantilever section of decks without barrier walls.

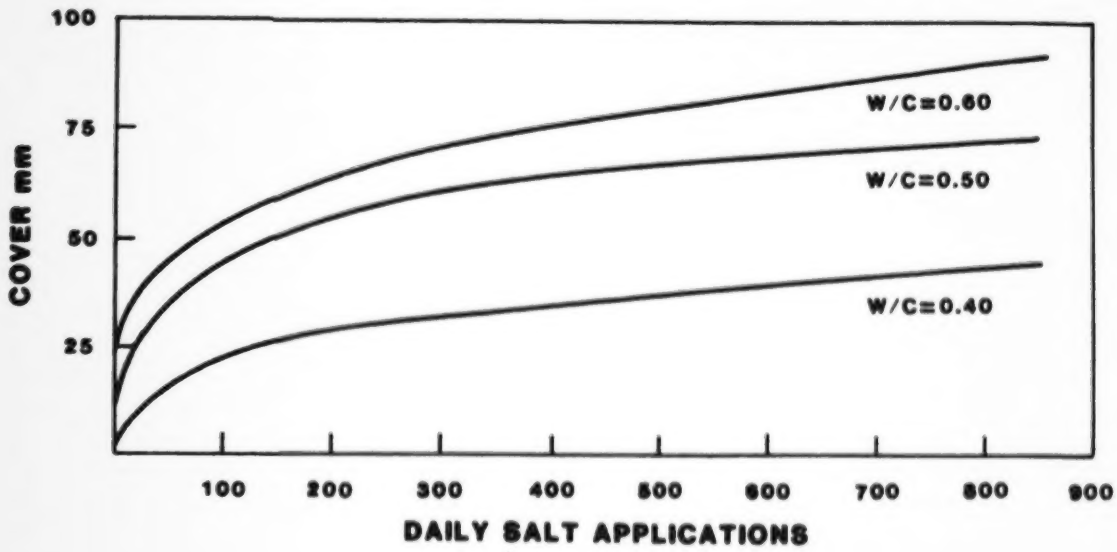
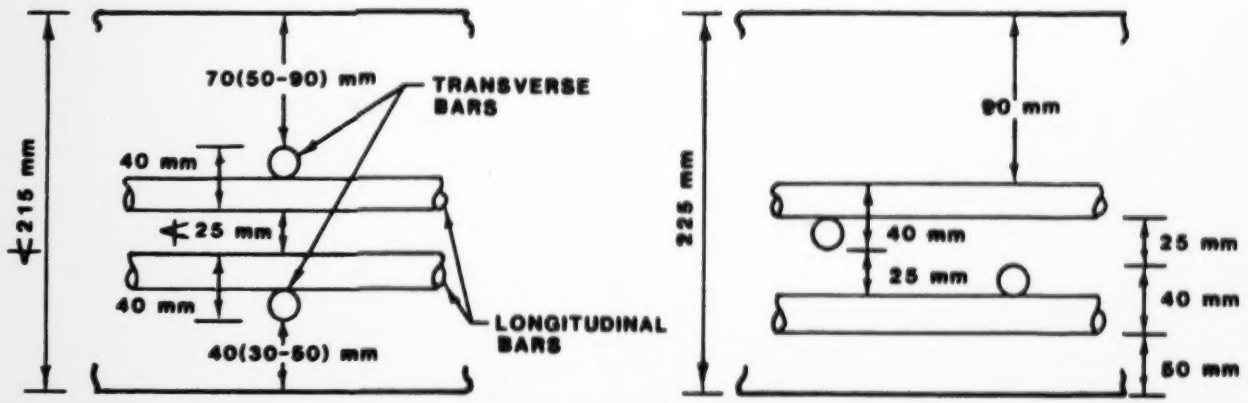


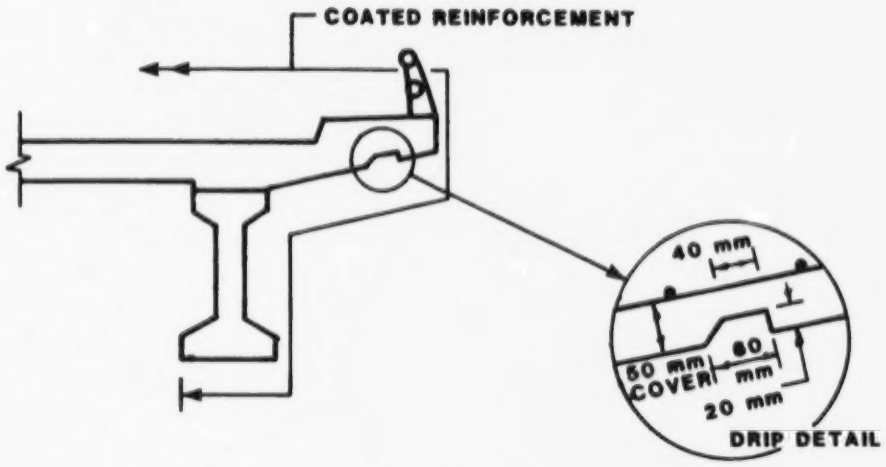
Figure 1: Effect of Water-Cement Ratio and Depth of Cover on Relative Time to Corrosion (10)



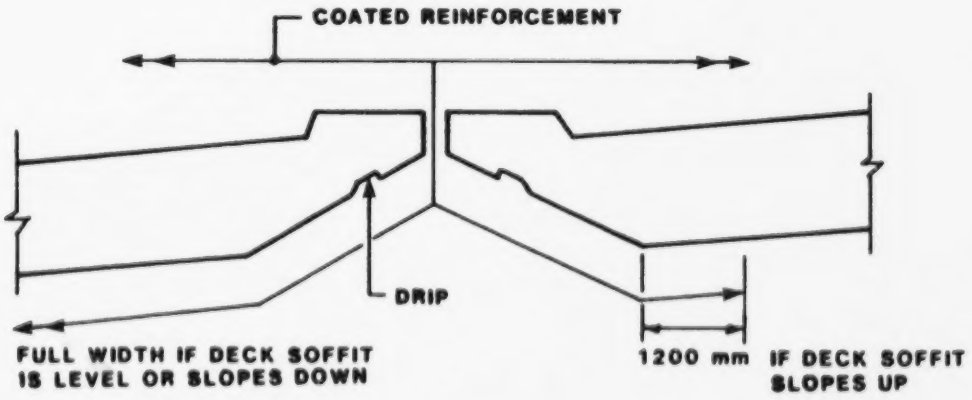
a) AVERAGE CONDITIONS

b) WORST CASE WITH LONGITUDINAL BARS STAGGERED

Figure 2: Tolerances for Location of Reinforcing Steel in Thin Slab Bridge Decks



I CONCRETE GIRDERS AND SLAB DECKS



II THICK SLABS WITH OR WITHOUT VOIDS

Figure 3: Requirements for Coated Reinforcement Below Sealed or Unsealed Longitudinal Joints or Below Open Railings

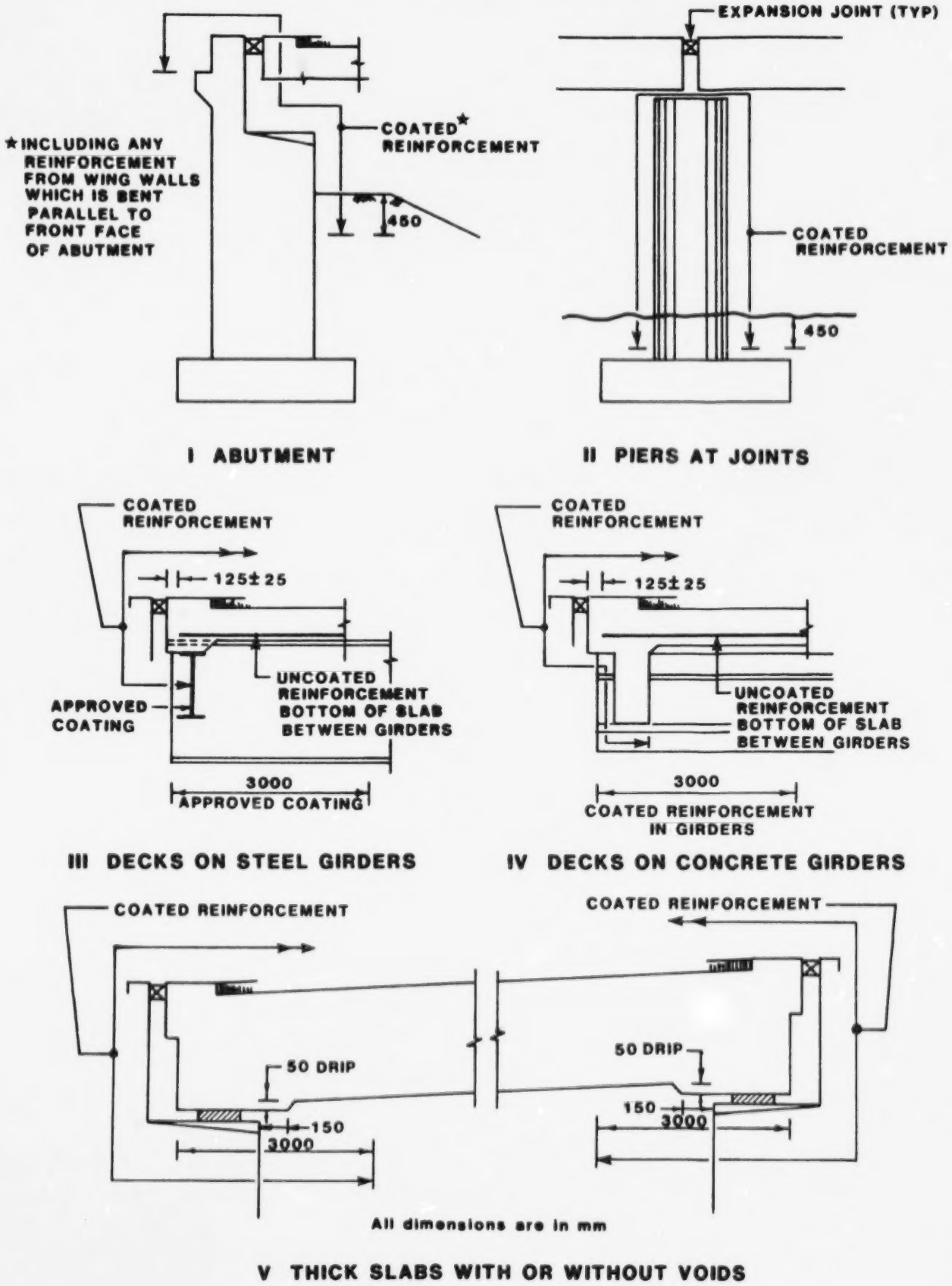


Figure 4: Requirements for Coated Reinforcement Below Sealed or Unsealed Transverse Joints